TechData Sheet

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Solar Water Heating --

Guidance for Small Facilities

Water heating accounts for a substantial portion of energy use at many Federal facilities. Of the total energy used, approximately 18 percent in residential and 4 percent in commercial buildings is for water heating; that percentage may be much higher for buildings with laundries, kitchens, showers, or swimming pools. Nearly all hot water in the United States is heated directly or indirectly through the combustion of some fossil fuel. Because of these dwindling, nonrenewable resources and stricter air pollution standards, it is recommended that Federal facility managers investigate and take advantage of existing solar water heating technology.

This TechData Sheet is to help activity personnel determine the feasibility, reliability, and cost effectiveness of domestic solar water heating systems for small buildings. With this guide, an energy manager can evaluate the various system options available.

TECHNICAL BACKGROUND

Solar hot water heaters can be divided into two main categories:

- Indirect Systems
- Direct Systems

Indirect systems circulate a non-toxic food grade *antifeeze*, such as propylene glycol, through the collector and later use a heat exchanger to transfer the heat collected by the solution to the potable water. Systems of this type were primarily developed for applications where freezing either at night or during the winter months posed a problem and draining of the collector water was either inconvenient, impossible, or cost prohibitive. Although such systems allow the implementation of solar hot water heaters in almost any climate, they lose in heating efficiency - about 10 to 14 percent, due to the heat exchanger.

Direct systems on the other hand, move the potable water to be consumed directly through the collector, thereby avoiding the efficiency loss associated with the heat exchanger. Although some manufacturers provide both manual and automatic draindown or recirculation features to avoid water freeze up, it has been found that such designs are not as reliable as indirect methods of freeze protection.

Within the above categories, there are three types of solar water heating systems manufactured today:

- Batch or no-flow systems
- Passive or natural-flow systems
- Active or forced-flow systems

As depicted in Table 1, each system offers distinct advantages and disadvantages according to the kind of hot water required and its subsequent use.

Batch or no-flow systems are direct systems that are by far the simplest and least expensive methods for producing hot water. Primarily used in residential applications, they are reliable, simple to install, and can provide 50 to 90 percent of hot water needs depending on use and climate.

Batch heaters, often referred to as integral collector storage (ICS) units because the water reservoir serves as both the storage tank and the collector (Figure 1), are comprised of an insulated outer shell with a reflective inner lining and usually two transparent glass or plastic covers that allow penetration of solar radiation. Inside the shell is a stagnant black metal reservoir containing about 30 to 80 gallons of water to be heated. The container is filled with water in the early morning and allowed to sit and collect incident radiation as well as that reflected from the shell's lining. Maximum temperatures are obtained when the water is allowed to absorb solar heat undisturbed throughout the day. Such systems are usually roof

Table 1. Comparison of Solar Water Heating Systems

Type	Achievable Temperature Max (°F)	Simplicity	Typical Application	Capital Cost and Maintenance	Energy Required	Solar Category
Batch	120	Simple	Domestic hot water Preheat	Inexpensive	None	Direct
Passive	180	Moderate	Domestic hot water	Moderate	None	Direct Indirect
Active	220	Complex	Domestic hot water Industrial process	Expensive	Electrical	Direct Indirect

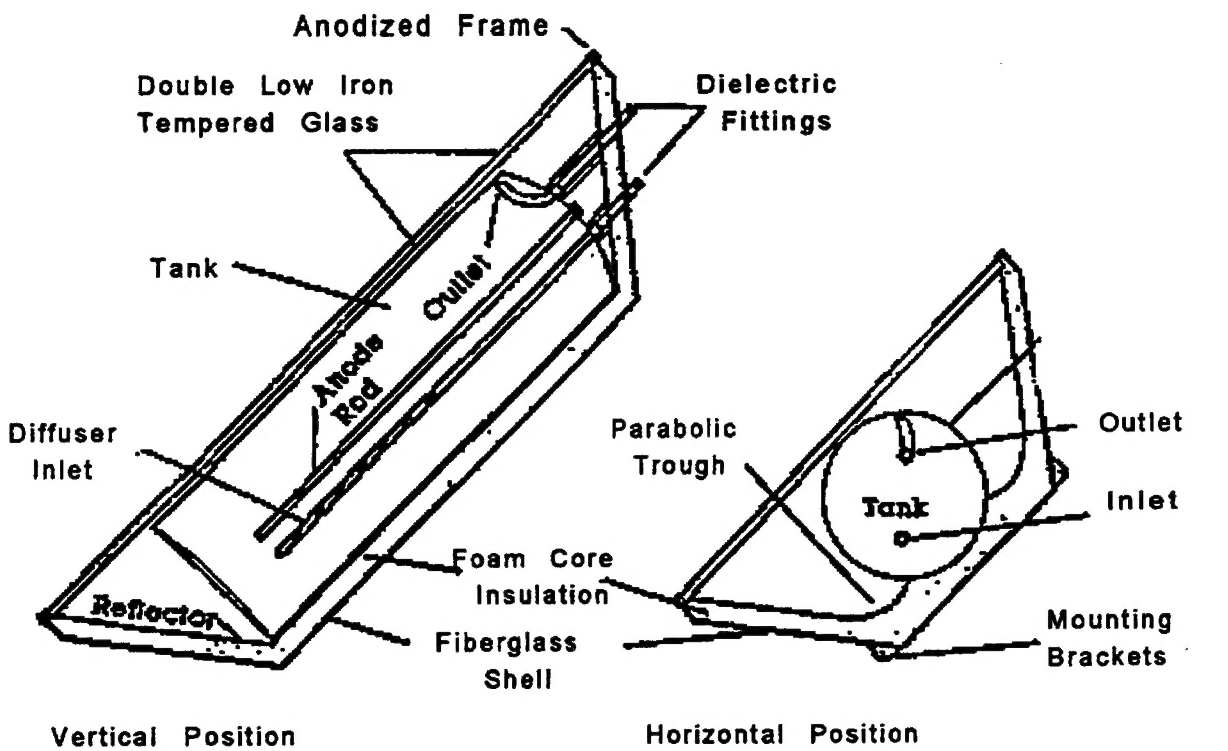

Figure 1. Typical batch water heater.

mounted and may require additional structural support to handle the weight of the tank. Implementation of batch solar water heating systems, unless in the tropical sunbelt region where nighttime heat loses are minimal and temperatures are constantly warm, will generally not produce noticeable energy or cost savings. Other disadvantages associated with these heaters are:

(1) They are limited in the temperature they can achieve, 120°F being the limit of their summer time performance capabilities.

(2) Hot water cannot be produced quickly because a large mass of water is being heated at once. Such collectors reach their maximum temperature sometime in the afternoon.

(3) Substantial amounts of energy will be lost as the water cools if not used when it is at its maximum temperature.

(4) Storage tank size limits, the amount of water that can be heated and may not be aesthetically pleasing.

These disadvantages may turn out to be irrelevant if you have an application occurring at the end of the day or if the water load fluctuates and frequent periods of no use are expected. In addition, small loads, such as those found in residential homes (one to two bedrooms), provide the best opportunities, especially if located in the sunbelt region (35° on either side of the equator) where the climate is mild to hot and the desired water temperature low (<120°F).

Passive systems offer increased flexibility and can be designed to operate in either an indirect or direct configuration, allowing implementation in virtually all climatic conditions. Passive or natural-flow systems work on the principle that as a fluid absorbs energy it becomes hotter, lighter, and less dense. This natural convection of hot fluid rising and cold fluid falling occurs only when the solar collector is located below the storage tank. A typical thermosyphon configuration consists of a fully insulated metal storage tank coupled with a flat plate solar collector (Figure 2).

Cold water enters the bottom of the collector and absorbs heat as it rises through the copper tube heat exchangers. The increasingly hot and buoyant water reaches the top of the collector and flows into the insulated storage tank where it can be stored for use at any time. This self-regulating process continues throughout the day until useful energy can no longer be extracted. Increased effectiveness is achieved with this system because the circulation of water enhances the heat transfer capacity of the overall process. This results in more water being heated in a day's cycle as compared to the batch heaters. Because of this, passive systems can be operated in a broader range of climatic conditions, not necessarily limited to the sunbelt region, and still provide moderate to excellent cost and energy savings. Larger scale applications, such as dormitories and hotels, could use this system as long as roof support is considered. These units tend to be heavy since the collector and storage tank are both roof mounted. Although a passive system is relatively inexpensive, very reliable, and has no operating costs or expensive control mechanisms, there are some possible disadvantages associated with its implementation:

(1) The collectors may require freeze-protection (heat transfer fluid) measures in certain geographical locations (above or below the sunbelt region).

(2) A roof-mounted storage tank above the collectors may not be aesthetically pleasing and may require additional structural support.

(3) The slow motion of hot water through the collector piping may cause an accelerated buildup of mineral deposits, resulting in diminishing system efficiency and eventual blockage depending on the water quality.

(4) The lack of a constant load will produce overheating problems.

(5) The system is somewhat inefficient due to the low flow rates in the convective loop(s).

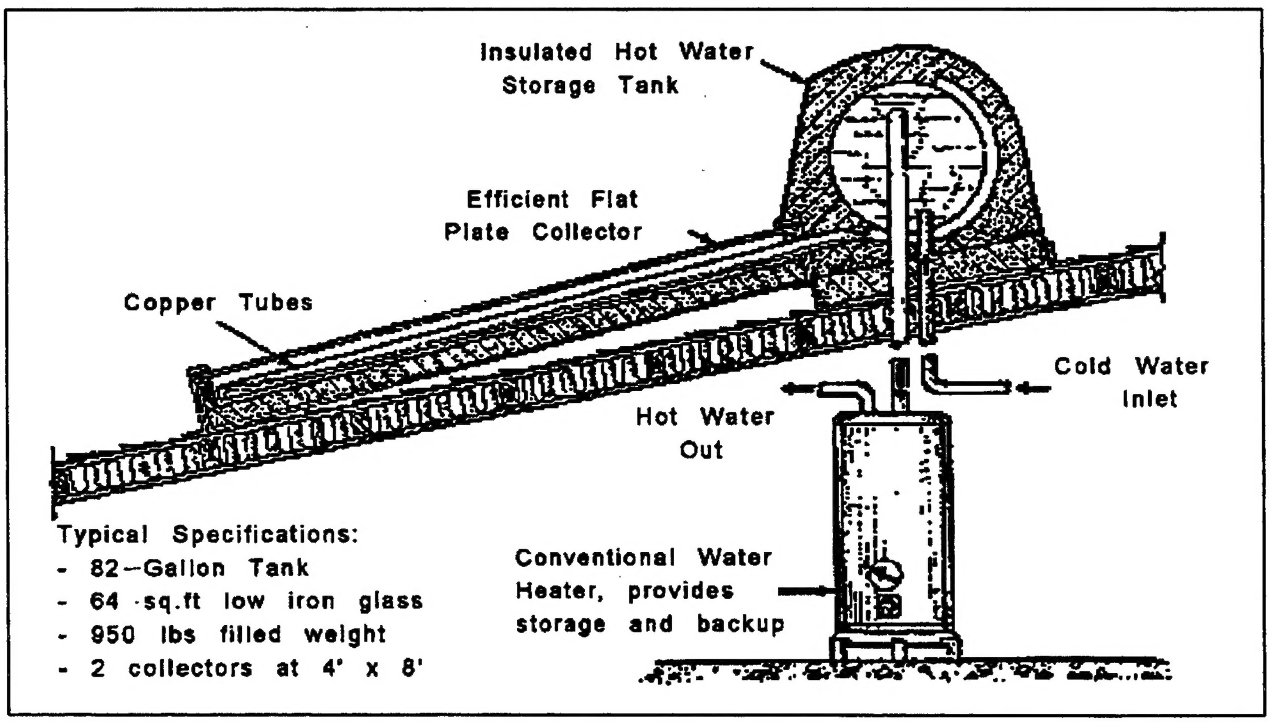

Figure 2.
Typical passive solar hot water heater.

Thermosyphon systems (like batch heaters) are appropriate in mild, sunny climates but can also be used in more temperate zones because of their higher efficiencies and better insulation. Capable of producing higher temperatures (compared to batch heaters), these systems can better accommodate larger residential homes (three to four bedroom) that require hot water throughout the day and whose daily, weekly, and yearly loads remain relatively constant.

As with passive systems, the active systems can accommodate freezing conditions by operating in a direct or indirect configuration. Using a mechanical pump and controls to achieve the water circulation process is what differentiates an active or forced-flow system from a passive one (Figure 3). Cold water is piped from the bottom or coldest part of the tank to the pump. The pump circulates the water to the solar collector where it is heated then routed back to the top of the storage tank for use at any time. The pump can be controlled by a differential monitor, which senses both the temperature at the collector and lower part of the tank. Water circulation occurs when the collector's temperature is greater than tank temperature indicating that there is enough solar energy for heating. Using a pump does two things to improve the passive design:

- Maximizes collection efficiency by precisely controlling the water flow rate through the collector according to climatic conditions.

- Allows for convenient location of the storage tank irrespective of collector elevation, removing the requirement of a roof-mounted storage tank inherent in batch and passive units.

Apart from increased aesthetics, the active system also offers:

- An accelerated water flow, which reduces excess mineral deposit buildup.

- Easy expansion in modular fashion to meet an increased load, such as dormitories and hotels.

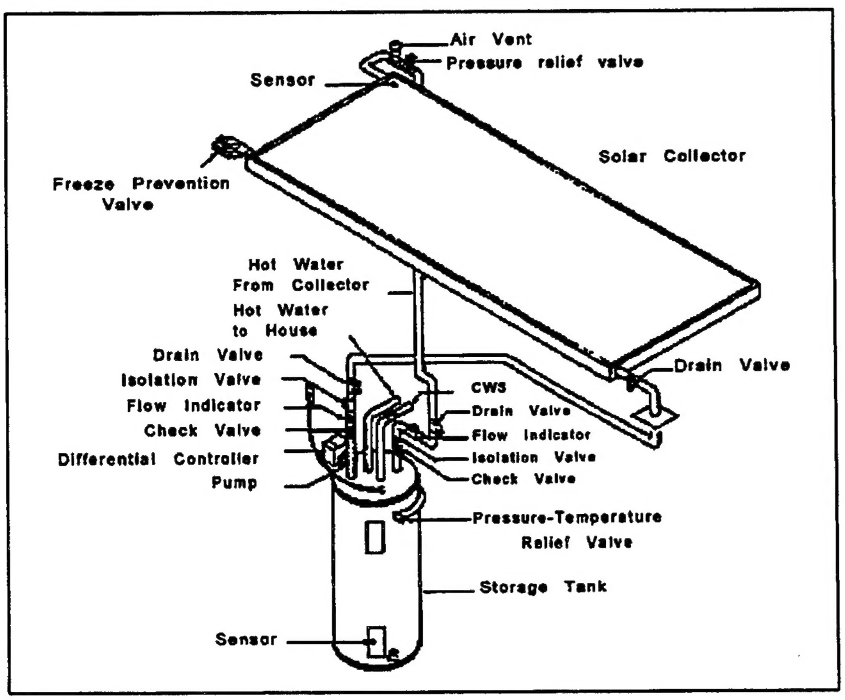

Figure 3. Typical direct active system.

- The flexibility enough to work in either cold or warm climates.

Active solar heaters not only increase the control and effectiveness of a system but introduce new complexities as well. The following lists some of the drawbacks encountered when operating such a system:

(1) The system is prone to pump failure and subsequent overheating.

(2) The control system is prone to failure.

(3) Freeze protection adds to the complexity, reliability, and maintenance.

(4) Increased technical complexity equals greater capital and maintenance costs.

The inherent modular flexibility of such a system allows it to be used in small homes (low temperature) as well as large dormitory or institutional situations where high water temperatures are needed. Active systems are the only alternative for applications where structural roof support is inadequate or aesthetics is of concern. Effective performance can be expected in virtually all climates (from freezing to very hot conditions) as long as a constant daily and weekly load is available.

SITE SELECTION

Three basic factors dictate the suitability of a solar water heating system in any given situation:

- Design parameters, such as solar radiation, capacity, temperature, time required and load reliability

- Maintenance

- Economics relative to conventional heating methods

Design Parameters

Solar systems should be designed and sized for the individual hot water requirements and radiation availability of each application. One size does not fit all. A system sized to meet the needs of a family of four in a tropical climate may be undersized for the same family living in

a hotter by day/cooler by night location. A simple and useful estimate of daily hot water consumption for domestic housing facilities is provided in Table 2.

Table 2. Daily Hot Water Consumption*

Load Type	Consumption/Day
Bathing/Bathroom	15 - 20 gal/person
Kitchen/Dishwashing by hand or Dishwasher	3 gal/person 15 gal
Washing Machine	4 gal/person

*These estimates are based on general rules of thumb and are not site specific. Consumption patterns vary and should be tailored for your location.

Based on estimated daily consumption values, the number and size of solar collectors can be determined as well as the storage tank capacity. For example, many solar hot water designers use the following:

Storage Capacity = (Daily Consumption Value) x (Storage Factor)

Collector Area = (Daily Consumption Value) x (Collector Factor) ft^2 /gal

The storage factor is usually a number between 1 and 1.5 and is strongly dictated by the amount of average solar insolation received in the area. In general, the collector factor is less than one (between 0.5 - 0.85) because systems are more cost effective if sized to meet 60 to 90 percent of the year-around demand. Generating these numbers can help estimate initial size, price, and cost effectiveness of a probable project. A **word of caution**, even the most accurate sizing criteria will not guarantee effective system performance unless the condition of load reliability is addressed. Hot water use should be relatively constant throughout the week to ensure proper water cycling, component operation, and cost effectiveness. The daily pattern of use affects the storage and collector area required of the uses that demand hot water in the afternoon or evening (such as laundries, lunch, or dinner), only food services will require relatively less storage than showers, where the heaviest demand occurs in the morning. In every application a constant load is critical to prevent overheating, acidic fluid transformation, leaks, and subsequent collector degradation. The best systems in the most ideal locations have failed due to this lack of consideration. The above factors are critical to avoiding past Naval solar thermal catastophies, which have been a direct result of sizing miscalculations, stagnant systems, and non-existent maintenance.

Maintenance

Maintenance is an inevitable characteristic of virtually every solar hot water system. The amount of maintenance required depends on the complexity of the system. For a simple system, such as a batch system, normal maintenance involves keeping the collector transparent covers clean, checking that piping is not blocked, etc. It is estimated that neglected collectors that gather dust and dirt for several years operate at reduced efficiencies on the order of 30 percent of their clean glass value. Occasionally, a cover glass will break and must be replaced before rain has a chance to damage the collector's interior.

One can usually expect a combination of problems and failures resulting in increased maintenance for systems of great complexity, such as active indirect applications. These systems introduce both mechanical and electrical components such as pumps, sensors, and controllers and provide a greater probability of failure. Pumps and externally exposed sensors may have to be replaced within the first 5 to 6 years of system's installation as the continuous temperature and cycling stresses of a solar systems operation take effect. All manufacturers recommend that preventative maintenance include general cleaning and inspection at least three to four times a year. For this reason, available maintenance resources can often play a significant role in the selection of a passive solar water heater over an active one. This is the strongest reason for keeping the system as simple as possible.

Economics

It is estimated that the installed cost of a solar hot water system ranges from \$45 to \$70/ft^2 of collector area. Considering single family domestic homes require anywhere from 42 to 64 ft^2 of collector area, most capital investments would be between \$2,000 and \$4,800. The comparison becomes pointless when compared to a \$180 natural gas water heater. That is why solar water heating economics are most favorable when compared with electric water heating or where fossil fuel costs are relatively high; however, it will vary, depending on geographic location, maintenance, and utility programs. In areas where natural gas is cheap and abundant, and electrical energy inexpensive, it is difficult for a solar hot water system to produce paybacks any less than 7 or 8 years*.

It should be noted that even with low rates, solar water heating may still be cost effective, as some utility companies are encouraging solar water heating as a demand side management strategy with possible rebate incentives. Several utility companies all across the country - from the sunbelt to the midwest and northeast - offer a variety of programs to reduce the initial cost of solar systems - including financing. Even with the mediocre paybacks, a solar system becomes feasible, which when properly installed and maintained, it can

*Solar pool heating often provides a payback as low as 2 years.

last anywhere from 10 to 30 years - far beyond the payback period. In turn, the utility comapnies avoid the cost of installing additional generating capacity, which helps them comply with ever increasing restrictions on air emissions.

Table 3 demonstrates why the alternative cost of water heating is one of the most important factors in determining the economic feasibility of a solar hot water system. It is far easier to save on electric (more than four times as expensive) or propane (nearly twice as expensive) water heating than it is on natural gas water heating.

Table 3. Comparison of Facility Energy Cost*

Energy Type	Average Cost ($/MBtu)
Electricity	22.09
Propane	8.59
Fuel Oil	5.14
Natural Gas	4.55

*Source: Table 2-20, page 77 of the Annual Energy Review, Commercial Buildings Energy Consumption and Expenditure Indicators, Selected Years, 1979-1992. Cost data for 1992, except for propane which is for 1986.

Interestingly, solar hot water is equally viable throughout the country, even in cold climates. This is because having colder water to start with helps solar hot water economics. A solar collector performs more efficiently when heating water from 50°F to 100°F than it would be heating water from 75°F to 125°F, because less energy is lost to the cooler ambient air. Areas with less solar resources tend to have colder water supplies, and the two factors balance out. Although it is difficult to provide a precise cost analysis of domestic solar water heating applications, an attempt has been made to provide facility managers with an initial tool to screen probable projects. Based on your current energy charge, Figures 4 and 5 provide an approximate payback period for an active or passive system at various demand rates. Table 4 lists the assumptions made for each scenario.

Table 4. Assumptions for Economic Analysis

Parameter	Figure 4	Figure 5
System type	Passive Thermosyphon	Active
Number of people	4	4
Consumption w/dishwasher	95	95
System cost	$3,000	$4,500
Conventional energy form	Electrical	Electrical

For information regarding solar insolation at your location, refer to the Solar Radiation Data Manual available from the National Renewable Energy Laboratory (NREL) at (303) 275-4099 or contact NFESC at (805) 982-1368.

Indicators of a Probable Successful Solar Hot Water System

1. High conventional hot water fuel cost - electric or propane.
2. Large hot water load.
3. Steady hot water load demand - daily and throughout the year, or one that peaks in the summer.
4. Good solar insulation.
5. South facing roof, unshaded, and sunny.
6. A facility manager dedicated to the solar hot water project(s).

If you have any more questions about solar domestic hot water heating, call ***Mr. Mike Rocha at (805) 982-3597, DSN 551-3597, or Internet: mrocha@nfesc.navy.mil.***

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